

SUPERCHARGED EJECTOR RAMJET

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I. INTRODUCTION

System mission requirements consisting of broad Mach number and altitude operability impose severe and challenging demands on the propulsion system. A single thermodynamic cycle is incapable of satisfying these broad requirements. Therefore, it is desired to incorporate the best features of the appropriately selected propulsion elements, based on the mission requirements, into an integrated propulsion system. The Supercharged Ejector Ramjet (SERJ) is such a combined cycle. As reflected symbolically in Figure (1), the SERJ engine is comprised of three basic semi-independent subsystems: fan (compressor) supercharger system(s) driven by a small airbreathing gas generator, an ejector pumping system (E) and a ramjet (RJ) system.

Under Air Force Systems Command Sponsorship, significant exploratory development was achieved by Marquardt on a building block basis for the SERJ propulsion system. Following small scale rig testing of the basic cycle components in 1963, progressively improved 18-inch engine demonstrations were conducted on various propellants. These investigations have covered simulated flights from sea level to Mach 3. Fan, ejector and combustor tests continued through 1969 under IR&D, NAVAIR and USAF-APL sponsored programs.

The SERJ engine concept was experimentally evaluated in the supercharged ejector mode, the ramjet mode, the fan mode and the pure ramjet mode. The experimental results validated analytical performance predictions.

II. OBJECTIVES AND BENEFITS OF SERJ

The primary objective of a composite engine cycle, such as the SERJ, is to provide versatility of satisfying thrust requirements efficiently in a broad altitude-Mach envelope. This is accomplished by judiciously selecting one or more sub-elements of the engine without sacrificing their performance. High thrust levels for takeoff and climb-out is provided by the fan-ejector-ramjet operating mode. Efficient cruise performance is accomplished by the fan-ramjet mode for transonic and low supersonic speeds or by the ramjet for higher supersonic speeds. Super performance for high "g" maneuvers is instantly achievable by operating ejectors with the fan and/or ramjet.

With the multi-mode operating characteristics in mind, a typical engine operating envelope is presented in Figure (2). This chart shows the operating capability of the engine from zero to Mach 5 and from sea level to 140,000 feet altitude, operating with individual mode limits as indicated. As is shown at the various Mach number conditions, typically more than one operating mode is available depending upon the thrust demand and fuel efficiency (low specific fuel consumption) requirements.

The engine operational characteristics can be tailored to any specific system requirements. The inherent SERJ performance and operational flexibility makes it a superior propulsion system than one element engines such as a rocket or a turbojet.

III. GENESIS OF THE SERJ ENGINE

Integration of the ramjet and liquid rocket powerplants is fundamental to the concept of the composite propulsion system. The Ejector Ramjet engine is an elemental composite system which has been studied by Marquardt and found to be attractive for a number of high speed acceleration and cruise applications. Consideration of the practical aspects of aircraft flight profiles has led to the integration of a third element, the high bypass ratio lift/cruise fan. Inclusion of this component provides a capability for low speed, high efficiency aircraft loiter and intermediate flight speed operation. The Supercharged Ejector Ramjet, then, is a composite propulsion system integrating the three elements or subsystems as shown in Figure (3).

The individual technological bases for the rocket, the ramjet, and the fan components, insofar as the near term SERJ engine is concerned, exist at this time. Development problems then, are basically concerned with the integration of these subsystems to achieve an optimal aircraft powerplant.

IV. SERJ TECHNOLOGIES AND STATUS

The experimental component exploratory development and system feasibility level programs have been conducted by Marquardt since early 1960. In addition to company IR&D fundings, these programs were sponsored by Air Force-APL, Navy NAVAIR and NASA. These efforts continued to late 1960's and early 1970's. During this period component technologies were experimentally demonstrated. These components were later integrated into Ejector Ramjet (ERJ) and SERJ demonstrated hardware for concept evaluation and validation.

Typical component experimental programs are illustrated in Figure (4). Primary/secondary jet mixing (upper left) and afterburning following mixing and diffusion of the primary gases and the entrained air (lower left) were successfully performed. The results achieved in these early tests were highly favorable such that an 18-inch boilerplate engine was designed, constructed and operated in 1964.

Subsequently, hydrogen/oxygen rocket of boilerplate water-cooled construction were fabricated, individually tested (center picture) and installed in engine number 2, a freejet unit (right picture). This engine was tested in Marquardt's Cell 2 facility with freestream Mach number and altitude simulation. Hydrogen peroxide and hydrocarbon fuels were used as propellants.

In addition, the feasibility of a fan operation at high speeds including windmilling were demonstrated. The test results indicated the feasibility of windmilling fan at supersonic flight speeds with acceptable pressure losses. The feasibility of a wide operating range combustor concept was demonstrated over the anticipated engine operating envelope.

V. EJECTOR RAMJET ENGINE

The Ejector Ramjet is fundamentally simple in its physical make-up as shown in the schematic, Figure (5). Multiple primary chambers are located aft of the inlet diffuser at the forward end of the engine. High-energy primary exhaust gas is mixed with induced air in a constant area mixing section to increase significantly the air total pressure. The near-sonic mixed gases are then diffused to provide the highest practical static pressure at the afterburner inlet. Fuel is injected and burned in the afterburner section to consume the oxygen in the induced air. The resulting high pressure, high temperature gases are then expanded through an exit nozzle.

Cycle analyses, substantiated by experimental work, has shown that maximum performance is attained with stoichiometric (non-fuel rich) primaries to preclude combustion during the mixing process, with all combustion taking place in the higher pressure conditions in the afterburner.

The sea level static thrust and specific impulse of the Ejector Ramjet is significantly higher than the performance of a correctly expanded rocket engine, with the augmentation ratio increasing rapidly with increasing air speed. In general, the most effective operation favors gradual throttling or reduction of the primary flow between Mach 1.0 and Mach 2.0 to 2.5, after which the propulsion system operates on afterburner-only, as a conventional ramjet.

The engine was successfully tested in Marquardt's Cell 2 facility in 1966 with varying altitude and Mach number conditions.

IV. SUPERCHARGED EJECTOR RAMJET ENGINE

The SERJ engine is derived by integrating a fan supercharging system with an ejector ramjet engine. A conceptual SERJ engine design is depicted in Figure (6). The three major subsystems of the engine are the fan system, the ejector system and the ramjet system. The airbreathing gas generator and the ramjet are operated with JP fuel. Hydrogen peroxide was used for the ejector system.

The multiple nozzle ejector subsystem is located aft of the fan. High energy primary exhaust gases evolving from the decomposition of high pressure hydrogen-peroxide is mixed with induced air in a short mixing section to increase significantly the air total pressure and temperature, and to add additional free oxygen. The mixed gases are then diffused to provide the highest

practical static pressure in the ramjet combustor. Hydrocarbon fuel is injected and burned in the ramjet combustor section to consume the oxygen in the inlet air and that exhausted by the primary gas generator. The resulting high pressure, high temperature gases are then expanded through an exhaust nozzle.

The SERJ concept was demonstrated without the fan supercharger by simulating fan exit conditions (temperatures and pressures) at the ejector entrance plane.

VII. SERJ ENGINE CAPABILITY

Specific impulse for various thermodynamic cycles including the SERJ engine are compared in Figure (7). These individual cycles operate efficiently in a relatively narrow range of flight speeds. However, the SERJ cycle covers a much broader Mach number operating range as it can function efficiently in various modes depending upon the mission requirements.

At high flight speeds (Mach greater than 2), the ramjet cycle clearly indicates its superiority in specific impulse. However, at lower speeds its performance deteriorates very rapidly.

The SERJ cycle on the other hand covers this flight regime very efficiently. The engine provides a broad operational range in the ejector and the supercharged ejector ramjet modes of operation. As the thrust requirements decrease the specific impulse is improved at the specified flight condition by programmed throttling built into the engine. The fan/ramjet mode of operation provides the most efficient cycle resulting in very high specific impulse at low speeds.

The SERJ engine provides a versatile propulsion system to meet the mission thrust requirements most efficiently in a compact installation.

VII. CONCLUSIONS AND RECOMMENDATIONS

The SERJ engine is a highly flexible and promising composite propulsion system offering significant payoffs in high performance vehicle systems. Its basic subsystems such as fan, ejector and ramjet have been experimentally demonstrated. These components have also been integrated into engine demonstrators and tested in Marquardt Cell 2 facilities. This technical data base would result in a low risk and low cost propulsion system development program.

It is recommended that Marquardt's past SERJ related test data and studies be reviewed and updated by incorporating state-of-the-art technologies.



SUPERCHARGED EJECTOR RAMJET

Figure 1: Supercharged Ejector Ramjet (SERJ) is comprised of supercharger (fan), ejector and ramjet subsystems

TYPICAL ENGINE OPERATING FLIGHT ENVELOPE

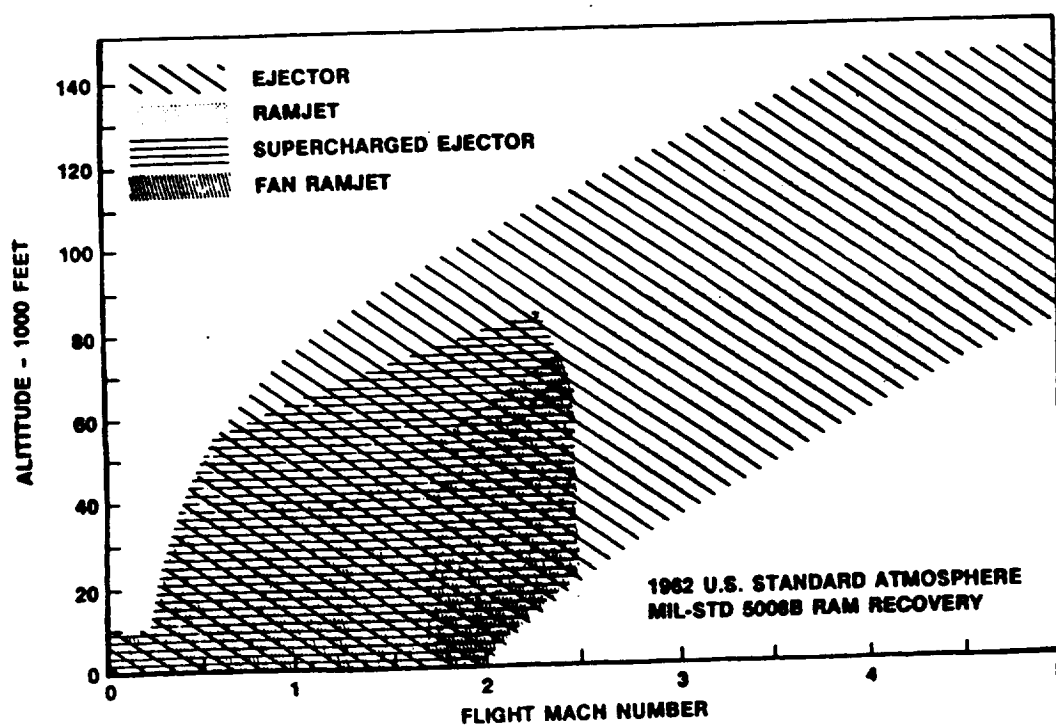


Figure 2: Typical SERJ engine operating flight envelope

GENESIS OF THE SERJ ENGINE

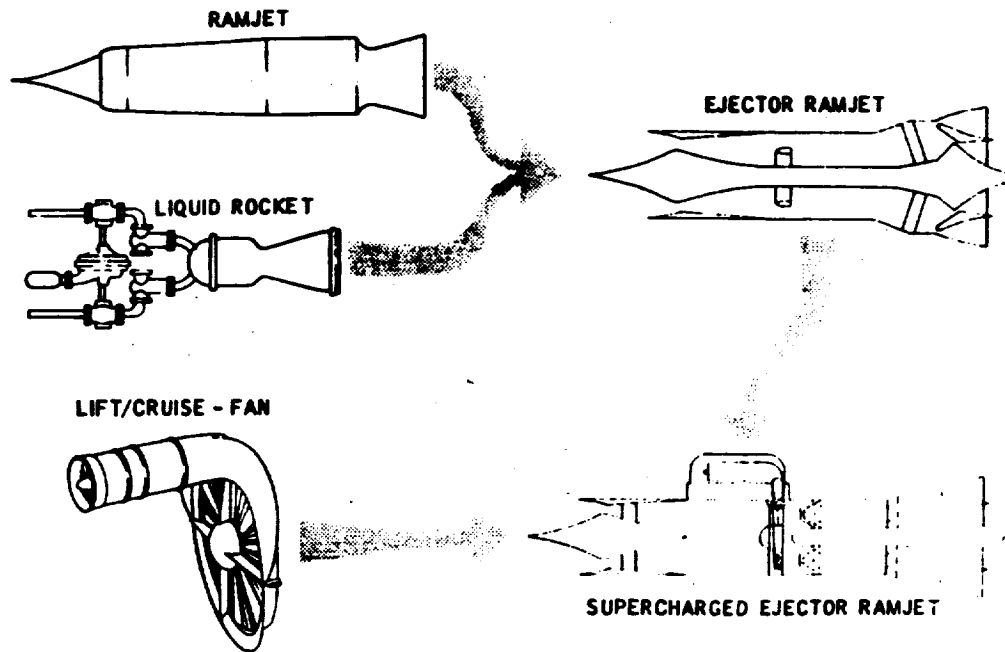


Figure 3: Genesis of the supercharged ejector ramjet engine

SERJ PREPARATORY EXPERIMENTAL PROGRAMS

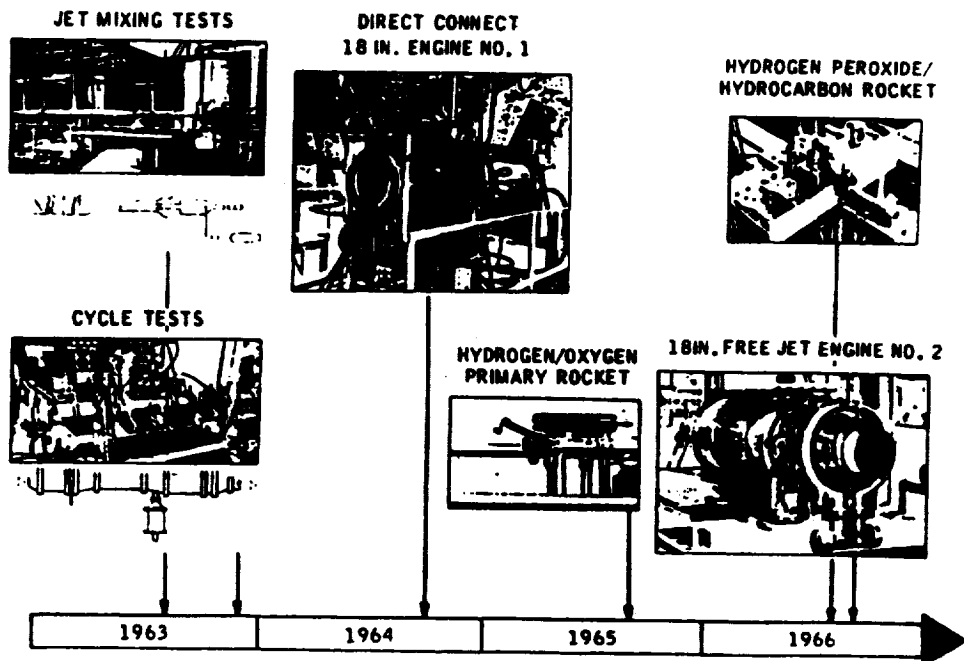


Figure 4: Examples of supercharged ejector ramjet component experimental programs

EJECTOR RAMJET ENGINE ELEMENTS

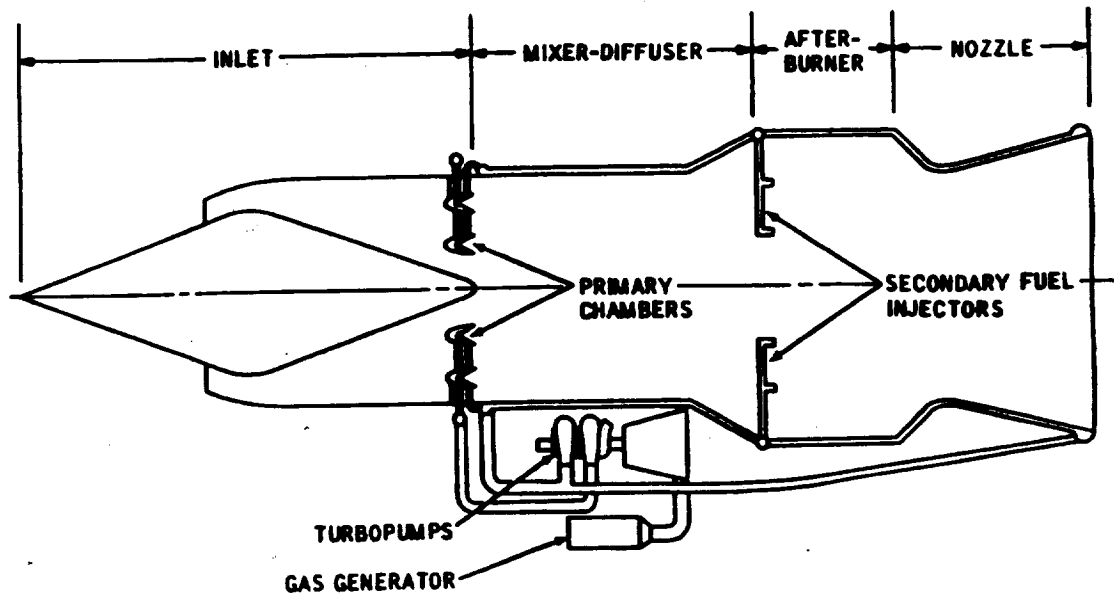


Figure 5: Typical ejector ramjet concept showing major subcomponents

PROPULSION SYSTEM SCHEMATIC (U)

SERJ - 176 ENGINE

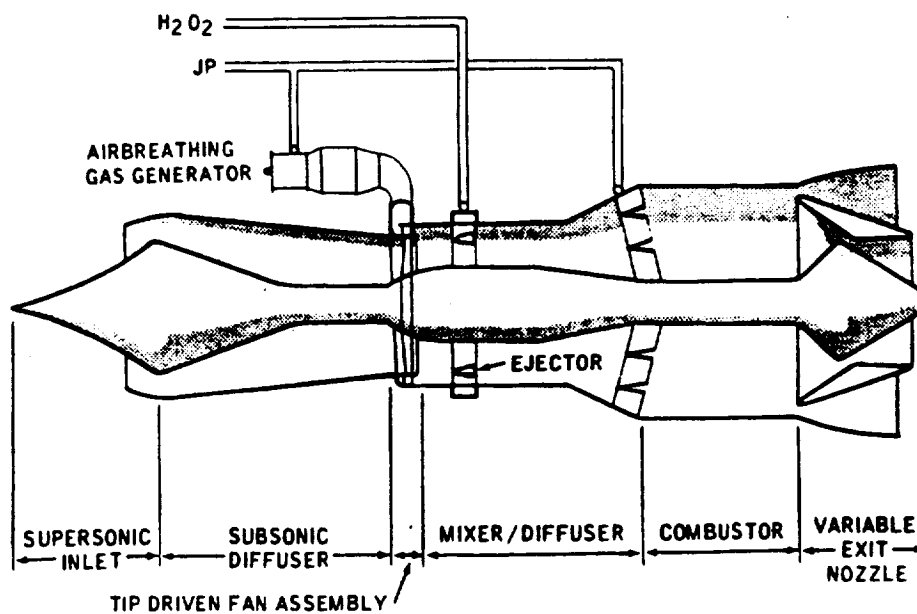


Figure 6: Typical supercharged ejector ramjet engine concept showing major subcomponents

TYPICAL PERFORMANCE TRENDS

HYDROCARBON FUELED ENGINES

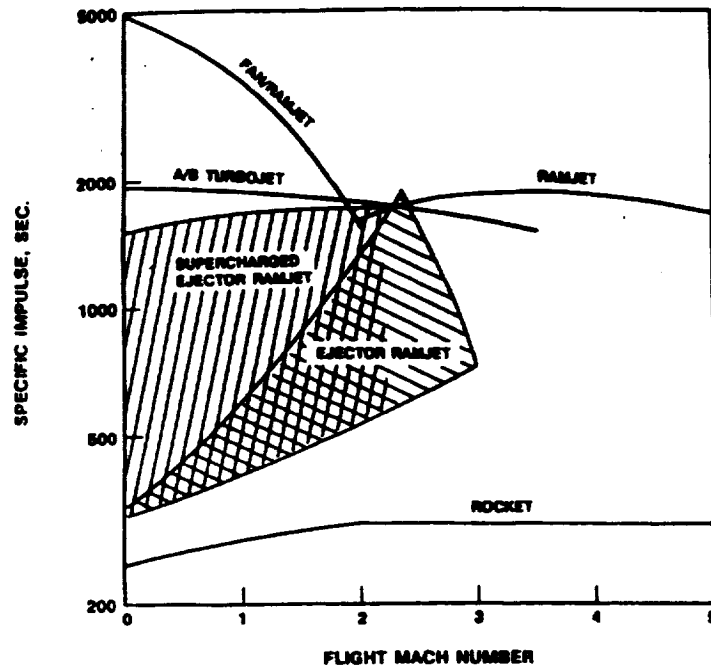


Figure 7: Typical engine performance trends with hydrocarbon fuel

RBCC Propulsion (Representative of Family Engines)

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(Paper Not Received in Time for Printing)

